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Control of Voltage-Reactive Power in Renewable Energy Power Plants

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Abstract— **The necessity for renewable production to contribute increasingly significantly to power system voltage and reactive power control has arisen as a result of the significant share of renewable power plants in the Romanian National Power System. The operation of a complicated, interconnected power system through secondary voltage-reactive power (U-Q) management requirements for renewable power plants is the focus of this paper's theoretical and practical contributions. These requirements were successfully implemented on subsystems that involve distributed energy resources and are condensed in a set of rules put out by the National Transport System Operator (TSO). Wind power plants that were plugged into the grid underwent a number of tests. The U-Q control laws were built on a comprehensive analysis of the substations where wind or solar power are connected to the national power grid.**

Keywords— ***voltage control; reactive power control; national dispatch center; renewable energy***

I. Introduction

Due to their abundance of energy and favourable effects on the environment, wind and sun are a free and limitless source of energy. Power system operators face a significant problem in maintaining control stability as a growing portion of the world's electricity is generated by massive wind and solar power facilities [1]. In order for many wind or photovoltaic power plants (WPP / PVPP) to function in a proper stable state, there are a number of technological issues that must be resolved.

Controlling the power fluctuation at the power plants' output is one of the key technological issues for WPP/PVPP operation [2]. The fluctuations in wind speed or sun radiation, which cause the varying power levels to be produced over time by the current generators/invertors, are what create the power fluctuation, regardless of the power demands during peak and off-peak hours. Power fluctuations can cause voltage variations at the grid's connecting point for large wind or solar power facilities [1]. Energy storage devices could be used as a solution to this issue, elements that can smooth the power fluctuation and subsequently, it will improve power distribution of the wind/ photovoltaic power plants maintaining stability control of power system when it is subjected to any voltage flicker.

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The reactive power control [3] in wind farm/photovoltaic power plants is yet another significant technical challenge. Based on the power created at various wind speeds and sun radiant, the quantity of reactive power produced or absorbed by the wind farm, photovoltaic power plants, and the grid changes. The size and number of wind farms and photovoltaic power plants that contribute to the energy production are expanding annually; it is impossible to disregard the reactive power generated by these large-scale facilities. Therefore, it is important to consider how the wind farm/photovoltaic power plants should be compensated for their reactive power.

II. Specific Requirements

TheNational Dispatching Center developed rules that were approved by the Regulatory Authority of Energy that detail the requirements for solar and wind power plants on the national grid (ANRE). The technical requirements for connection to the public electrical network for PVPP/WPP are outlined in the technical norm established by ANRE's Orders no. 30/2013 [4] and no. 51/2009 [5], respectively.

The ANRE's Order No. 74/2013 has approved the process for testing and certifying the functioning of wind and solar power plants.

A. GRID requirements for photovoltaic power plants (PVPP)[4,6]

When voltage dips and changes similar to those in Fig. 1 (low voltage ride-through) occur on one or more phases, dispatchable PVPP and inverters must be able to maintain grid connectivity.

Another crucial requirement for photovoltaic power plants (PVPP) with installed power greater than 1 MW is that the reactive power generated or absorbed by the PVPP must be able to be continuously adjusted to a maximum power factor of 0.9 inductive / capacitive on the voltages in the connection point located in the admissible range.

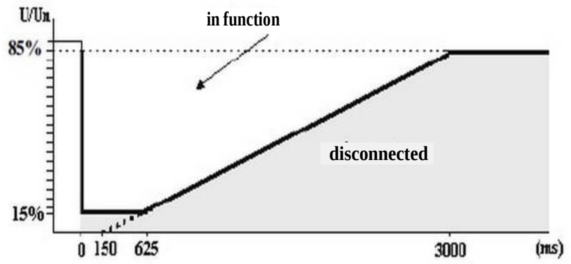

Fig. 1. The amplitude of voltage dips to which inverters/PVPP must remain in operation (Low Voltage Ride-Through)

PVPP must be able to do automatic voltage – reactive power control in the point of connection in any of the following ways:

- voltage control in point of connection;
- reactive power control changed with National Dispatch Center (NDC).

Also must provide reactive power exchange null when the power output is zero.

B. Grid requirements for Wind Power Plants (WPP) [5,7,8]

Wind Turbines must be able to remain connected to the grid in case of dips and voltage variations like those in Figure 2 (low voltage ride-through) on one or all phases.

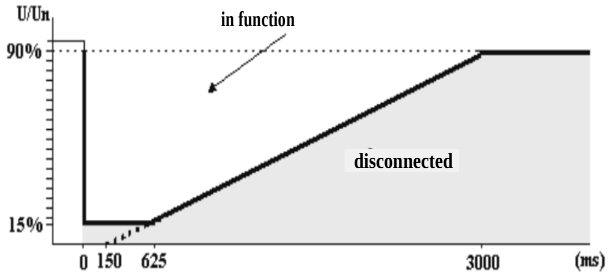

Fig. 2. The amplitude of voltage dips to which turbine/WPP must remain in operation (Low Voltage Ride-Through*)*

Another important requirement for WPP with installed power >1 MW is that on the voltages in the connection point located in the admissible range, the reactive power produced/absorbed by a photovoltaic power plant must be able to be adjusted continuously corresponding to a maximum power factor - 0.95 inductive / capacitive.

WPP must be able to do automatic voltage – reactive power control in the point of connection in any of the following ways:

- voltage control in point of connection;
- reactive power control changed with NDC;
- power factor control.

III. Voltage Control

Controlling the voltage of the electrical power system is crucial for preserving the stability of the system, preventing system blackouts, and ensuring that electrical power equipment is operated safely to avoid damage such motor and generator overheating. In general, low reactive power can cause voltage to rise whereas high reactive power can cause voltage to drop.

When there is an imbalance in the electrical networks' reactive power supply and demand, a voltage collapse happens. When a system provides less voltage, current must grow to keep up with demand, which uses more reactive power and further reduces voltage. Transmission lines go offline when the current gets too high, overloading other lines and perhaps leading to cascade failures. Transformers and other auxiliary components, like as generators, can also trip. In conclusion, it is important to counteract the detrimental effects of voltage collapse.

The three levels of voltage control in power systems are primary, secondary, and tertiary control.

The controllers of the generating sets provide primary voltage control, which tends to narrow the discrepancy between the actual terminal voltage and the actual scheduled (set point) value through their influence on the excitation voltage of the generator of the set. This control is offered within the generators' constructive parameters, as shown in diagrams P and Q, as well as the stability margin, which accepts a 10 percent deviation from the nominal voltage value. The time scale for primary control should be seconds, with a maximum of one minute [9,10].

After primary control, the secondary voltage control intervenes to return the voltage to its nominal level within minutes (200 to 300s). This coordinated control sets the reference levels for the primary controllers by acting on the available control equipment (battery connection or disconnection, on load tap changers, etc.).

In order to operate the system as efficiently and safely as possible, tertiary voltage control is responsible for adjusting and harmonising the various set point voltages to the pilot points in all networks. The national dispatching centre handles this control, and it runs in a matter of hours.

In this study, a coordinated voltage control for power networks incorporating renewable energy resources is discussed.

Through a network information system (NIS), the SCADA system oversees the network's operation while ensuring the various system operations, including the distribution management system (DMS), parameters state estimation (active, reactive power, cosij, voltage, etc.), and coordinated voltage control (CVC). Load, feeder capacitor, reactive power, and converter controllers are just a few of the controllers at play. Automatic Voltage Controller (AVC) relays on the tap changers of High Voltage/Medium Voltage (HV/MV) transformers are used as the primary control devices. The set point for AVC relays, as well as the capacitors and shunt reactors, are controlled by secondary voltage control.

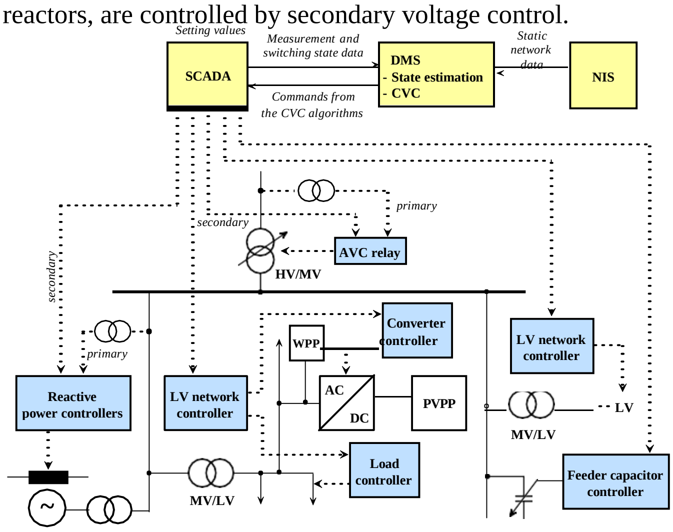

Fig 3. Cascade voltage control diagram

The grid requirements for the integration of renewable energy systems will be more stringent, and with it the control systems, due to the constant demand for clean and dependable electricity output from renewable energy systems (such as solar or wind turbine systems). As a result, the study starts off by discussing the unique needs for photovoltaic (PVPP) and wind turbine power systems (WPP).

The first step in achieving voltage control of a network region (secondary voltage control) is the fulfilment of the requirements surrounding the WPP & PVPP responsibility to provide voltage regulation inside the entire P-Q diagram (not connected to power factor value), [11].

When linking wind power plants, many voltage regulation requirements were enforced due to the variable nature of renewable energy sources' power supply (WPP) or photovoltaic power plants (PVPP), [4,5]. The main conditions to be fulfilled are the following:

• Automatically switching taps on HV/MV or MV/LV transformers. Both a fixed set point for the lower voltage and his range of fluctuation (values established in the tap change controller) and direct control of the tap changer from the substation master voltage controller are options for operating the tap changer (Automatic secondary voltage regulation - ASRU). The final solution was implemented in all 400/110 kV substations connected to WPPs controlled by NDC (Tariverde, ASRU controller; Rahman, ASRU controller; Stupina, Joint Controller; Siemens);

• Automatic and continuous calculus for the set points values for each WPP/PVPP. The computation is based on a real-time determination of the WPP voltage contribution and the apparent short-circuit power;

• The implementation of each WPP/PVPP P-Q diagram limit in the voltage controller;

Cosphi / Q / V measured

• Automatic substation topology knowledge and implementation in controller parameterization, considering the possibility of with the rules of adapting control in case of topology changes;

The operation of wind turbines/ invertors in voltage control mode is tested considering a sequence of variable set point of reactive power. The continuous adjustment of reactive power delivered by the WPP/PVPP contributes to the voltage level in the controlled area, Fig. 4.

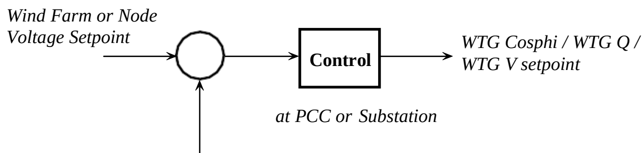

Fig. 4. Voltage control in case of wind power plants

Figure 6 displays an illustration of voltage management offered in the 110 kV Substation Tariverde in Romania. Through this substation, Fantanele WPP is connected to the electrical grid. The Fantanele WPP voltage response for the connection point voltage setpoint Uc is depicted in the figure. It is evident that a changing voltage reference (between 111,2 kV and 108,2 kV) results in a voltage response without shocks at the point of connection. Additionally, a stationary inaccuracy of 0.2% and a transitory time of 20 seconds are obtained. The voltage control system acts to bring voltage variations in PC voltage back to the predetermined value. Lines tripping and the disconnection/connection of shunt reactors are two examples of actuators for AVR control.

IV. Reactive Power Control

The primary method for controlling reactive power is voltage level measurement, with the reactive current component considered a disturbance [12].

Currently, the automatic setpoint values (Qref) sent from the local dispatch centre (LDC) in response to a DSO command govern reactive power control of WPPs and PVPPs. DSO determines the power plants' (connected in MV) voltage contribution (Vd) (Fig. 5).

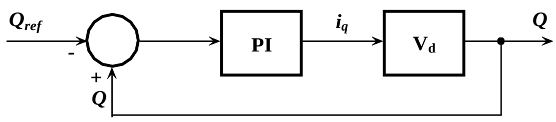

Fig. 5. Block diagram of reactive power controller in case of wind power plant (with PI controller)

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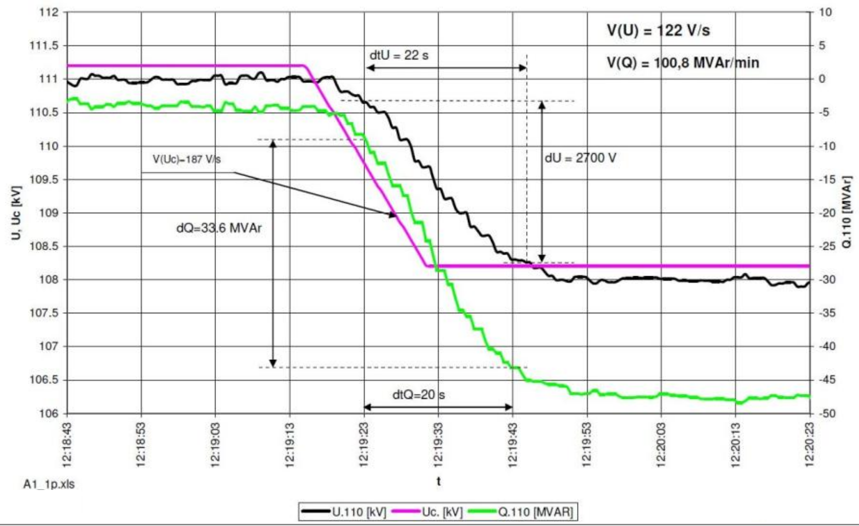

Fig. 6. **V**oltage control for a wind power plant connected in 400/110kV Substation Tariverde

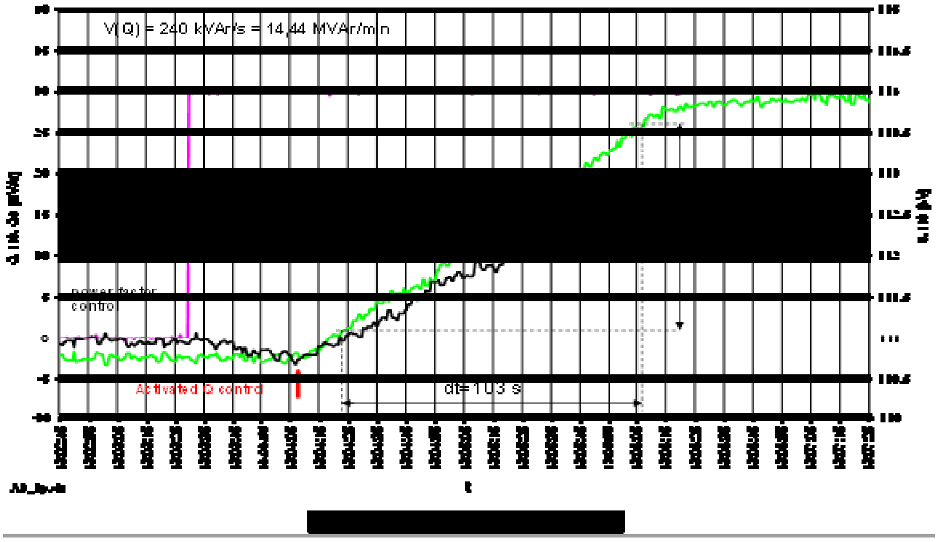

Fig. 7. Example of reactive power control and his voltage contribution – case of a wind power plant tests

Many times (like as in the Dobrogea region), WPPs with 5-10 MW that can adjust voltage are only employed in this control mode [13].
When connected to the HV of an HV/MV substation, WPPs or PVPPs larger than 10 MW operate in voltage control, but when connected to the MV bus bar of the same substation, they operate in reactive control mode (e.g. WPP Babadag 33,6 MW and 8 MW case). In keeping with this idea, if the technical capabilities of PVPP/WPPs connected in adjacent networks nodes with interdependencies, having higher control insensibility and small ramp rates in reactive power control, will be operated in reactive control mode and the voltage control will be supplied, as master operation, by the power more performing power larger P-Q diagram. The reactive power control operation could involve some negative aspects.

An example of reactive power control is presented in Fig. 7, that presents the response to a reactive power set point (from 0 to 30 MVAr) when Q control is activated for WPP. Time to response is good (103 seconds). The reactive power control is done properly for both inductive (presented case) and capacitive cases.

For reactive power control operation [14] is necessary to:

•Take in consideration the operational limits of WPP and inverters at LV level;

•Implement a proportional – integrative control law with anti-windup function;

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•Automat bound of the WPP reactive power for reaching the reactive limit of each wind turbine/inverter, or the limit of operation in the LV level;

•Computing the total WPP/PVPP P-Q diagram in the connection point and implement it for the reactive power control.

The reactive power control is basically the control used in case of voltage control for 400/110 kV substations.

V. Conclusions

It was necessary to adopt an approach that took into account the simultaneous connectivity of the national grid to the larger systems, the accelerated pace of adding numerous renewable power plants (especially WPPs) to the current grid, their geographic location within the national grid, and all other practical and technical requirements imposed by the interconnected operation of the power system (electrical energy quality, stability, etc.).

When the National Dispatch Center (NDC) developed a special set of conditions that allow the "friendly operation" of a sizable number of renewable power plants inside the already in place power system, all these factors were taken into account. NDC was fully involved in the proposal, elaboration, and promotion of new operating rules, control loops, protections, new technical solutions, putting them in operation, and monitoring their effects after a thorough and professional analysis of all new equipment and operational situations that occurred. The technical specifications served as the basis for testing equipment in the power grid, which provided an opportunity to test the authors' suggested hierarchical control system's organisational structure in Fig. 8.

The nine Local Dispatch Centres (LDC), which manage the PVPPs and WPPs, are directly under the TSO's management in this new dispatching system.

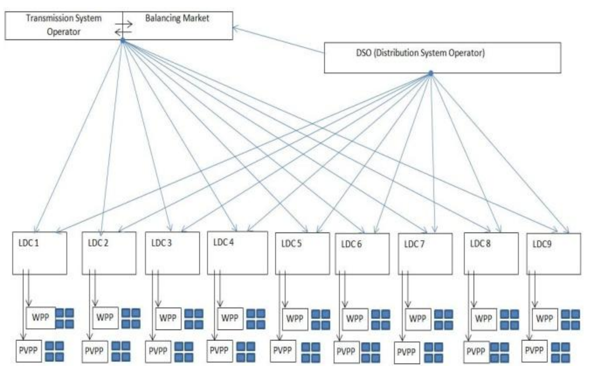

Fig. 8. Developed structure of dispatching wind power plants/photovoltaic power plants

The National Dispatch Center was crucial in the integration of renewable energy sources. NDC has streamlined the procedure and established controls and oversight frameworks inside the

caused by the issuance of more than 22000 MW acceptance certifications for connection into a system with a medium load of 6500–7000 MW, which already existed in a state of anarchy. The only way to maintain the security of the power

system under conditions of unpredictable generation development and a lack of network enforcement is through regulation of the generation, in accordance with technical and market rules, the monitoring of operation process and current behaviour.

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